ECE 322L
Electronics 2

04/16/20 - Lecture 22

Class A and class B amplifiers

Overview

- Classes of amplifiers

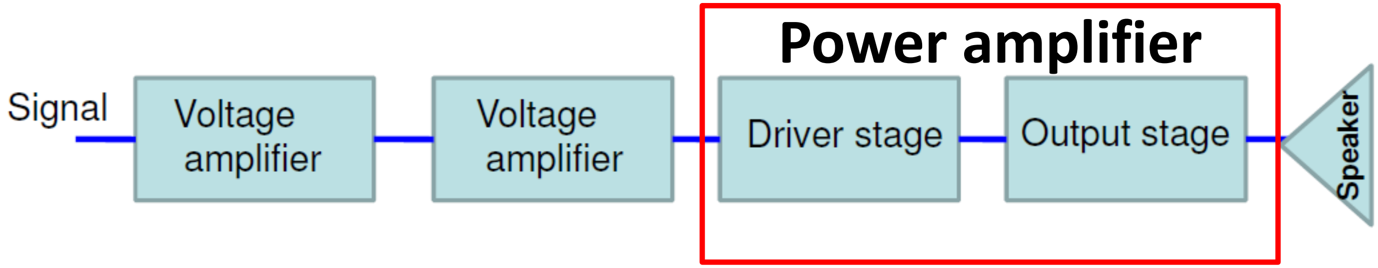
  (Neamen 8.3 and 8.4-S&S, 6th edition, 11.1)
- Class A power amplifiers

  (Neamen 8.3.1 and 8.4-S&S, 6th edition, 11.2)
- Class B power amplifiers

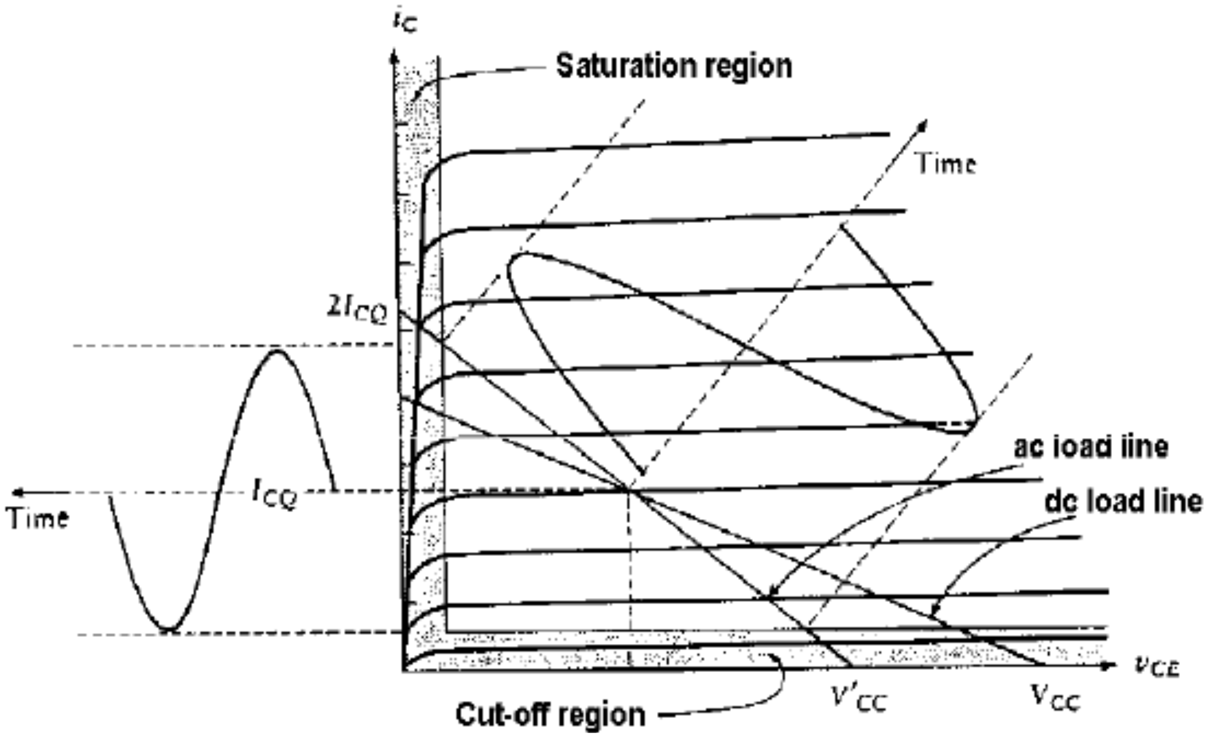
  (Neamen 8.3.2 and 8.4-S&S, 6th edition, 11.3)

Power amplifiers

- **Large-signal amplifier**
- **Generally the last stage of a multistage amplifier.**
- **The function of a practical power amplifier is to deliver high power to an output device, such as a loud speaker.**
- **Typical output power rating of a power amplifier will be 1W or higher. The schematic diagram of a multi-stage amplifier utilizing a power amplifier is shown below –**



Power amplifiers



A Power amplifier utilizes a large portion of the ac load-line.

As a result of the signal being large

- **distortion may easily occur**
- **the small-signal approximation cannot be used to calculate the parameters of the amplifier.**

Performance parameters of a power amplifier

- **Amplifier Efficiency :**

$$\eta = \frac{\text{signal load power}(\bar{P}_L)}{\text{supply power}(\bar{P}_S)}$$

Ratio of the average power transferred to the load and the average supplied power.

- **Total harmonic distortion (THD)**

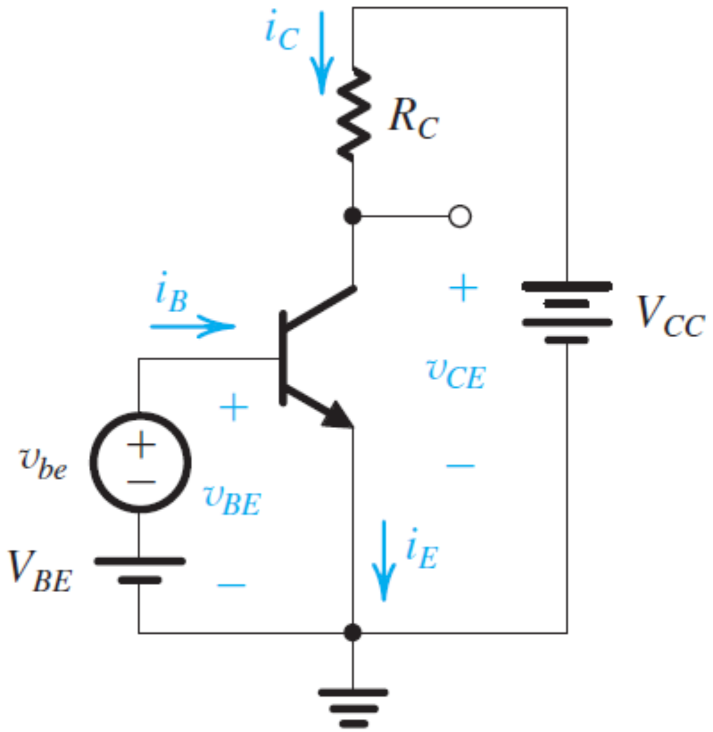
It quantifies the change in output waveform relatively to the input waveform.

- **Power dissipation capability**

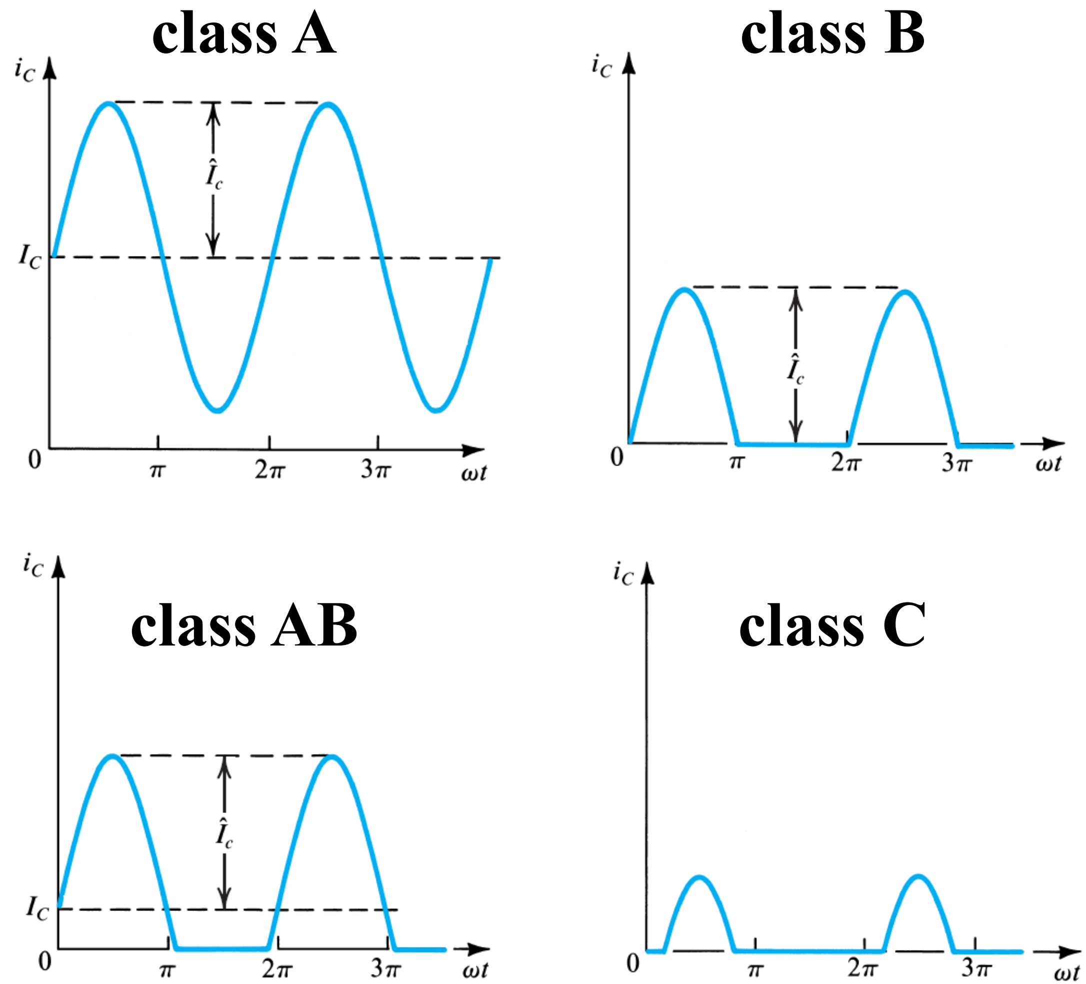
Ability of a power amplifier to dissipate heat.

Classes of amplifiers

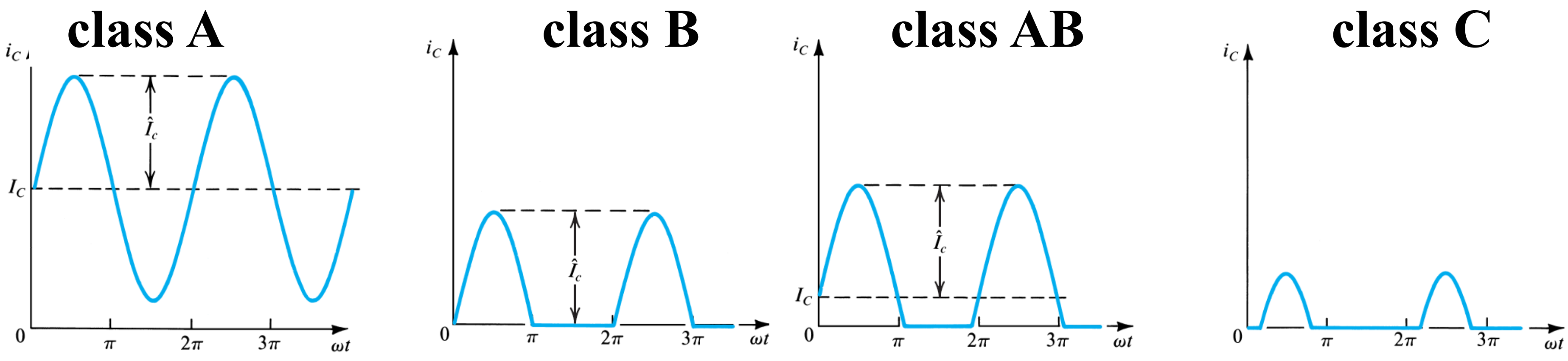
Amplifiers are classified according to the collector current waveform that results when an input signal is applied.



v_{be} **sinusoidal function**

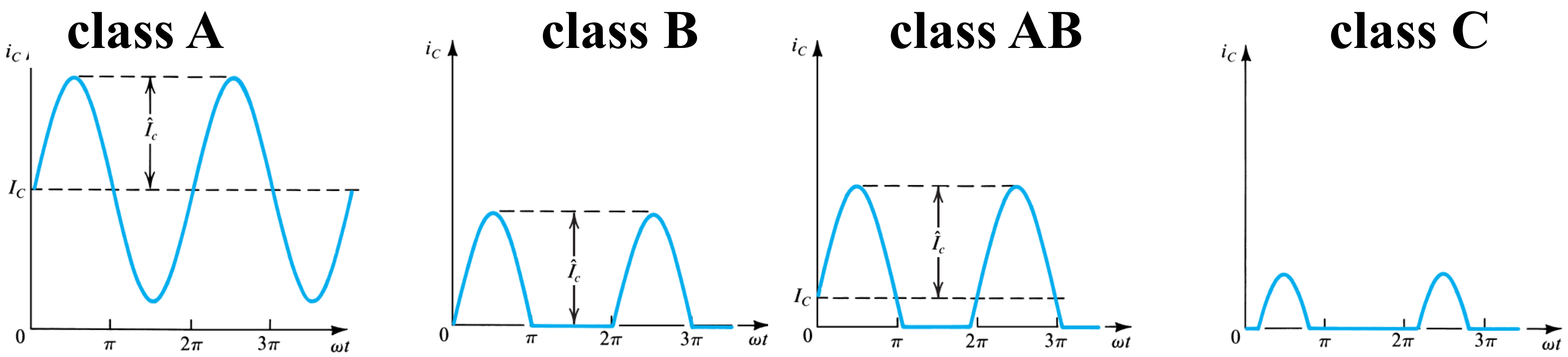


Classes of amplifiers



- **Class-A:** Output device(s) conduct through 360 degrees of input cycle (never switch off).
- **Class-B:** Output devices conduct for 180 degrees (1/2 of input cycle).
- **Class-AB:** Halfway (or partway) between the above two examples (181 to 200 degrees typical).
- **Class-C:** Output device(s) conduct for less than 180 degrees (100 to 150 degrees typical)

Classes of amplifiers

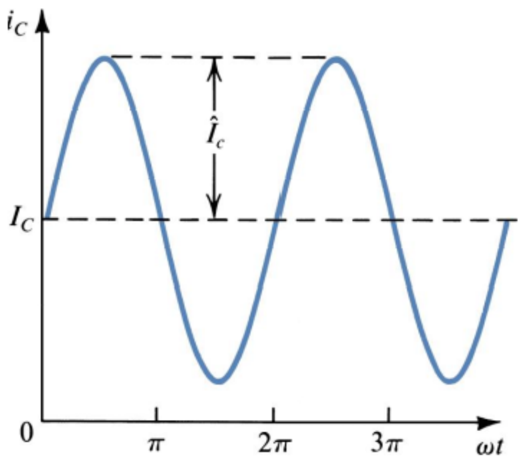


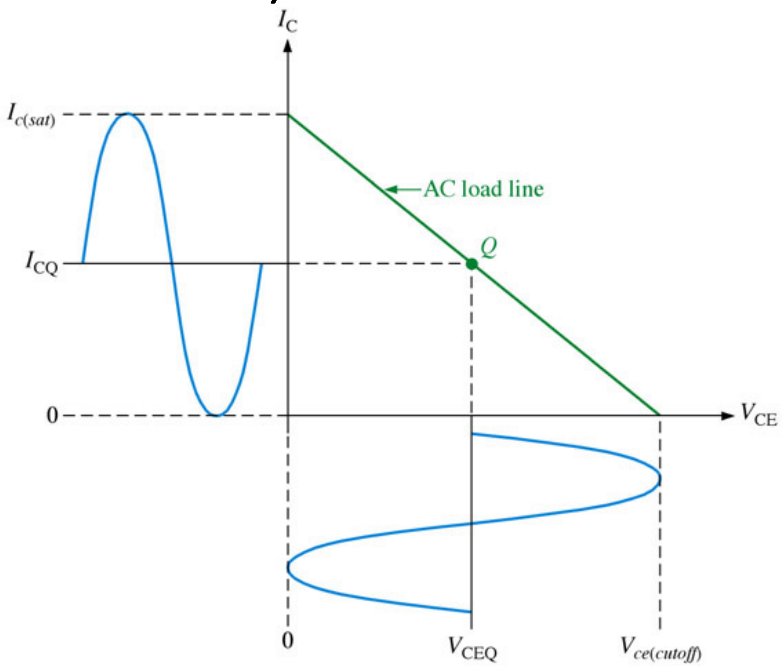
Each class is characterized by different values of performance parameters, namely efficiency, total harmonic distortion and power dissipation capability.

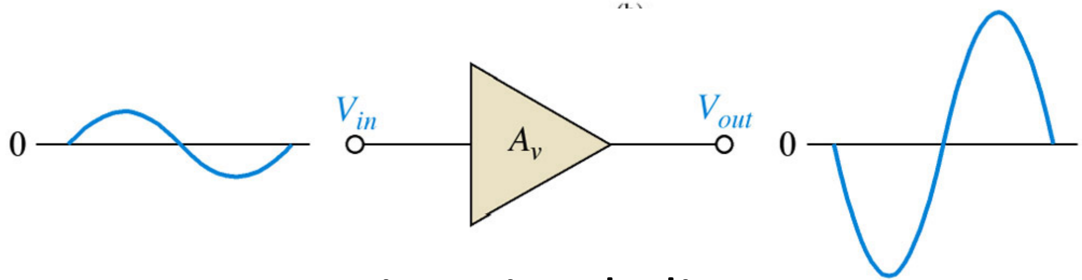
Hence, different classes of amplifiers are suitable for different applications/stages.

Class A amplifier

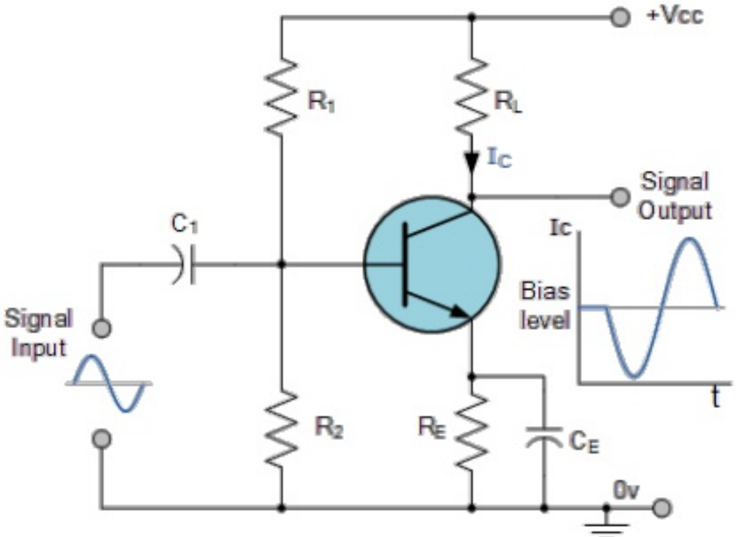
Class-A: Output device(s) conduct through 360 degrees of input cycle (never switch off).

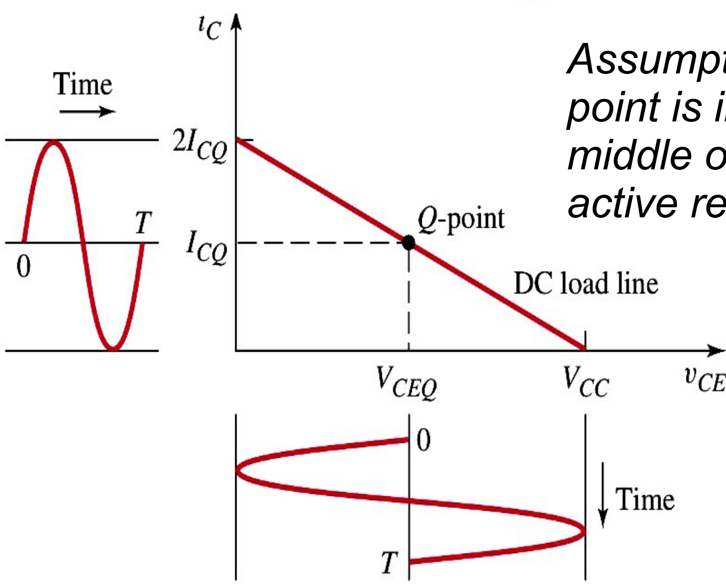






Class A output stage is a simple linear current amplifier.





Assumption: Q point is in the middle of the active region

$$\eta = \frac{\text{signal load power}(\bar{P}_L)}{\text{supply power}(\bar{P}_S)}$$

$$\eta_{max} = \frac{\bar{P}_{L,max}}{\bar{P}_S}$$

$$\bar{P}_L = V_{omax,rms} I_{omax,rms}$$

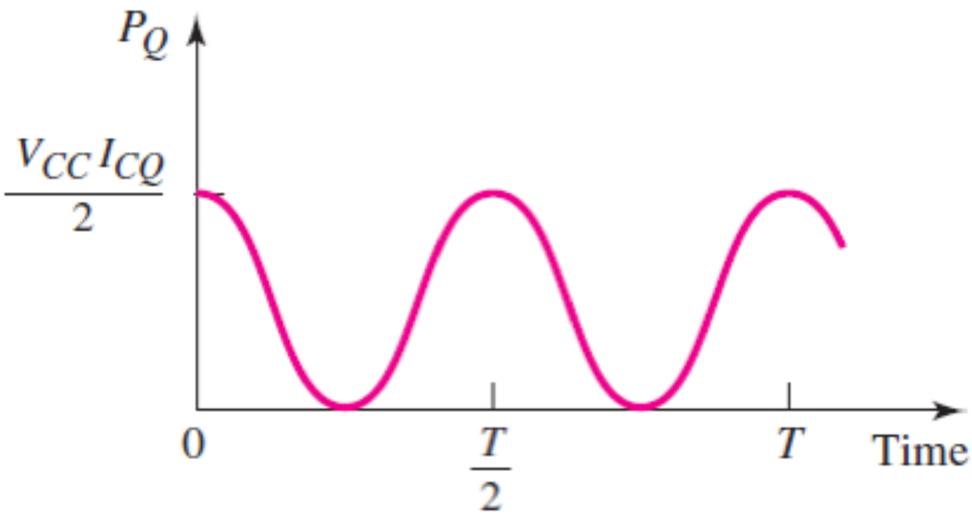
$$\bar{P}_L = \frac{V_{o,pmax}}{\sqrt{2}} \frac{I_{o,pmax}}{\sqrt{2}}$$

$$\bar{P}_L(\max) = \left(\frac{1}{2}\right)\left(\frac{V_{CC}}{2}\right)(I_{CQ}) = \frac{V_{CC} I_{CQ}}{4}$$

$$\bar{P}_S = V_{CC} I_{CQ}$$

$$\eta(\max) = \frac{\frac{1}{4} V_{CC} I_{CQ}}{V_{CC} I_{CQ}} \Rightarrow 25\%$$

Instantaneous power dissipated by the transistor



$$p_Q = v_{CE} i_C$$

$$i_C = I_{CQ} + I_p \sin \omega t$$

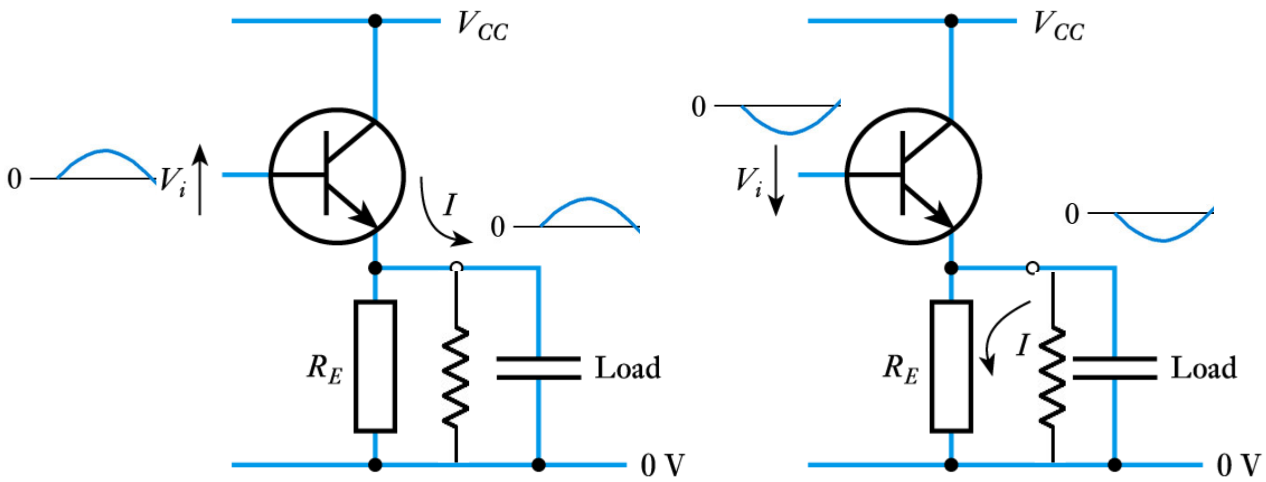
$$v_{CE} = \frac{V_{CC}}{2} - V_p \sin \omega t$$

$$p_Q = \frac{V_{CC} I_{CQ}}{2}(1 - \sin^2 \omega t)$$

- ➢ It is independent on the amplitude of the output signal
- ➢ The BJT must be continuously able to handle the maximum dissipated power

Why is class A so inefficient ?

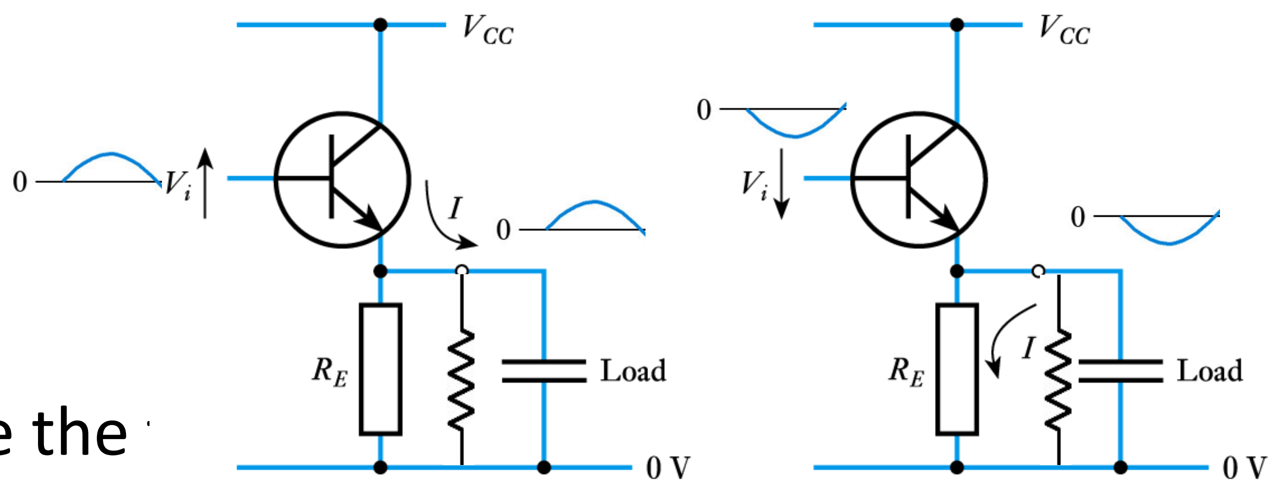
The load applied to a power amplifier is not simply resistive but also has an inductive or capacitive element.



As a result power is only supplied to the load during half a period. In the other half of the period the load supplies power to the biasing network.

Why is class A so inefficient ?

Single transistor can only conduct in one direction. Hence the biasing network dissipates the power supplied by the load.



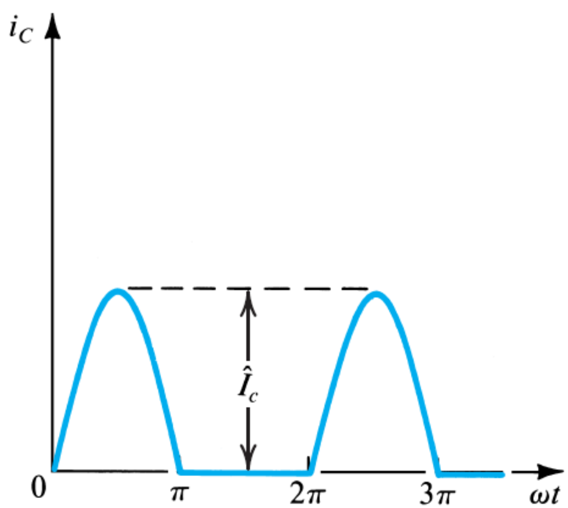
While the uring the whole period of the input signal, power is only transferred to the load during half a cycle.

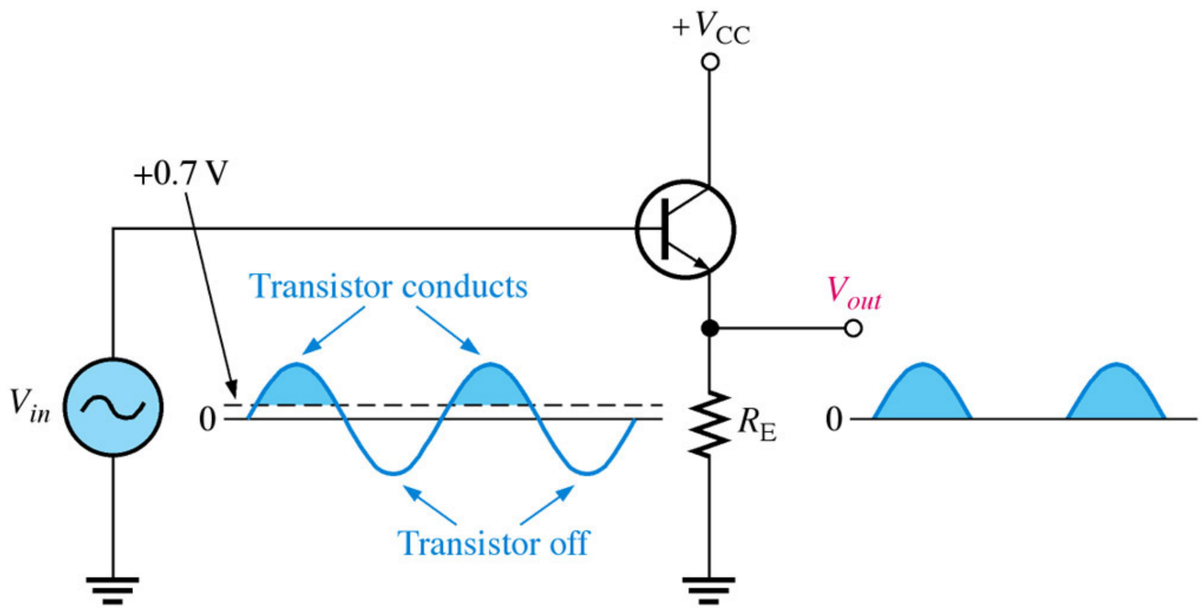
Class A amplifier

- A class A amplifier is a simple linear amplifier.
- It is also very inefficient, typical maximum efficiency is between 10 and 20 %.
- Only suitable for low power applications.
- High power requires much better efficiency.

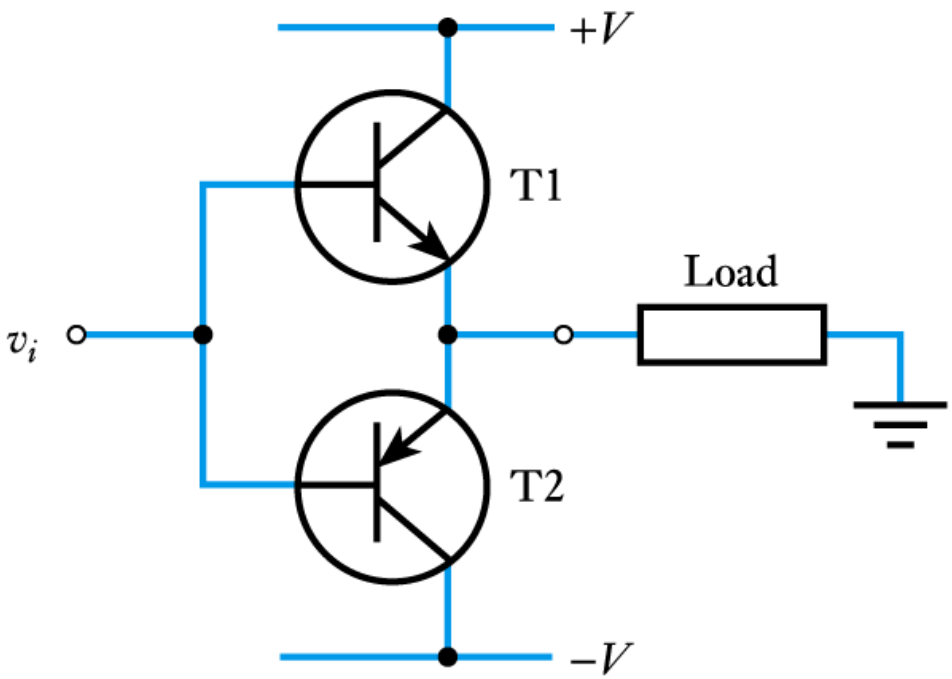
Class B amplifier

Individual output devices conduct for 180 degrees (1/2 of input cycle)





Useful implementation of a class B amplifier

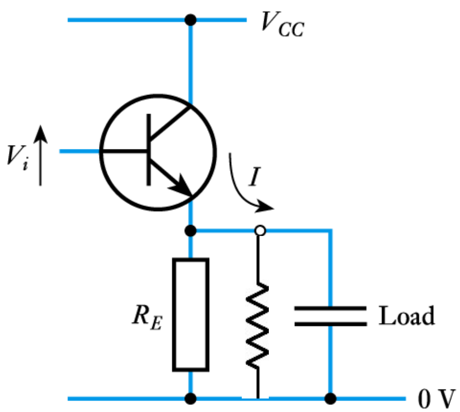


This circuit is both a good current source and a good current sink

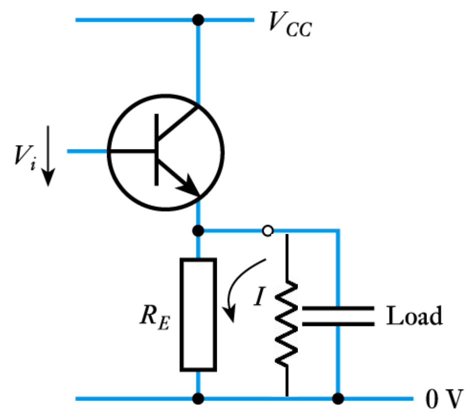
Class B amplifier

Useful implementation of a class B amplifier

npn is a good current source **npn is a bad current sink**

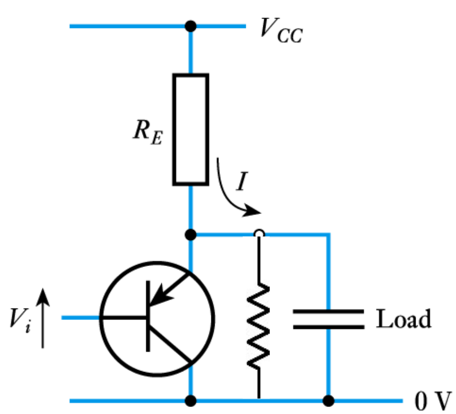


(a)

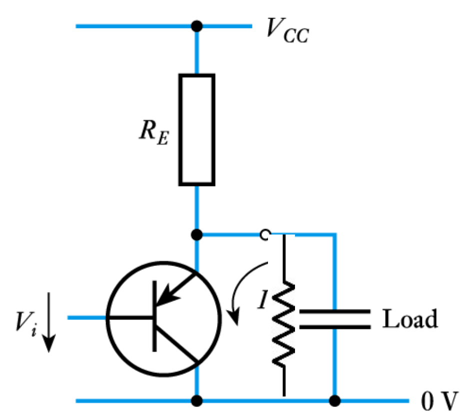


(b)

pnp is a bad current source **pnp is a good current sink**

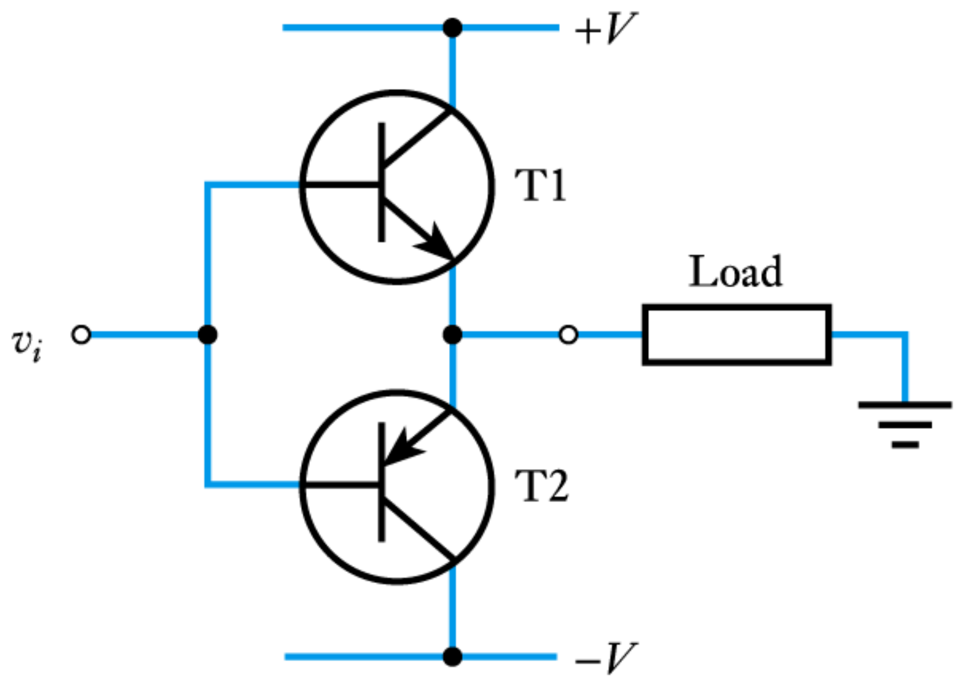


(a)

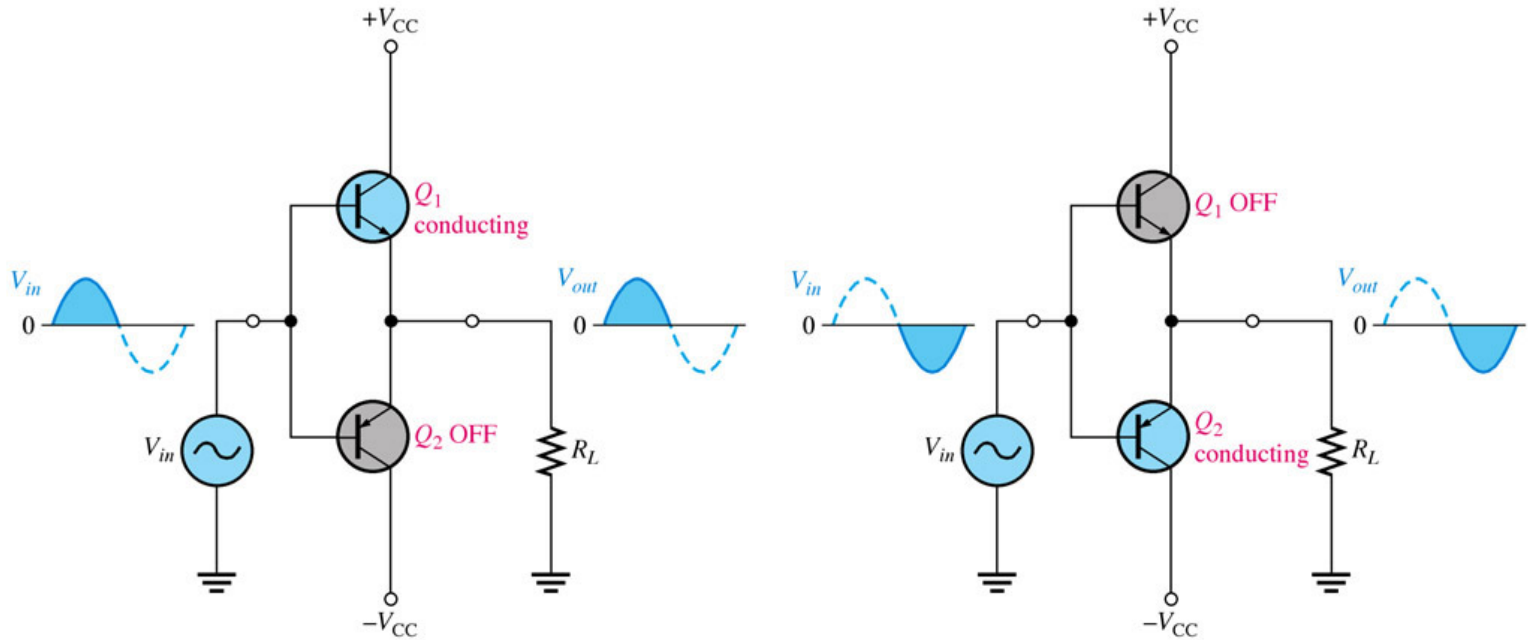


(b)

Useful implementation of a class B amplifier



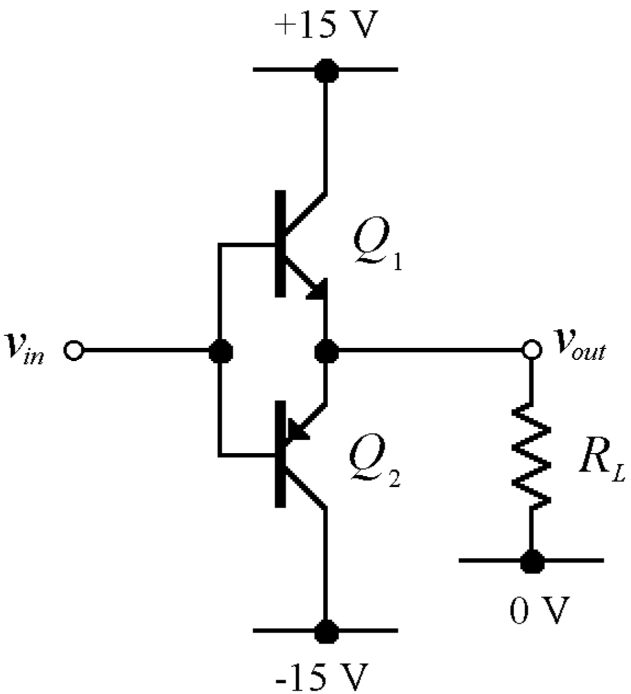
This circuit is both a good current source and a good current sink

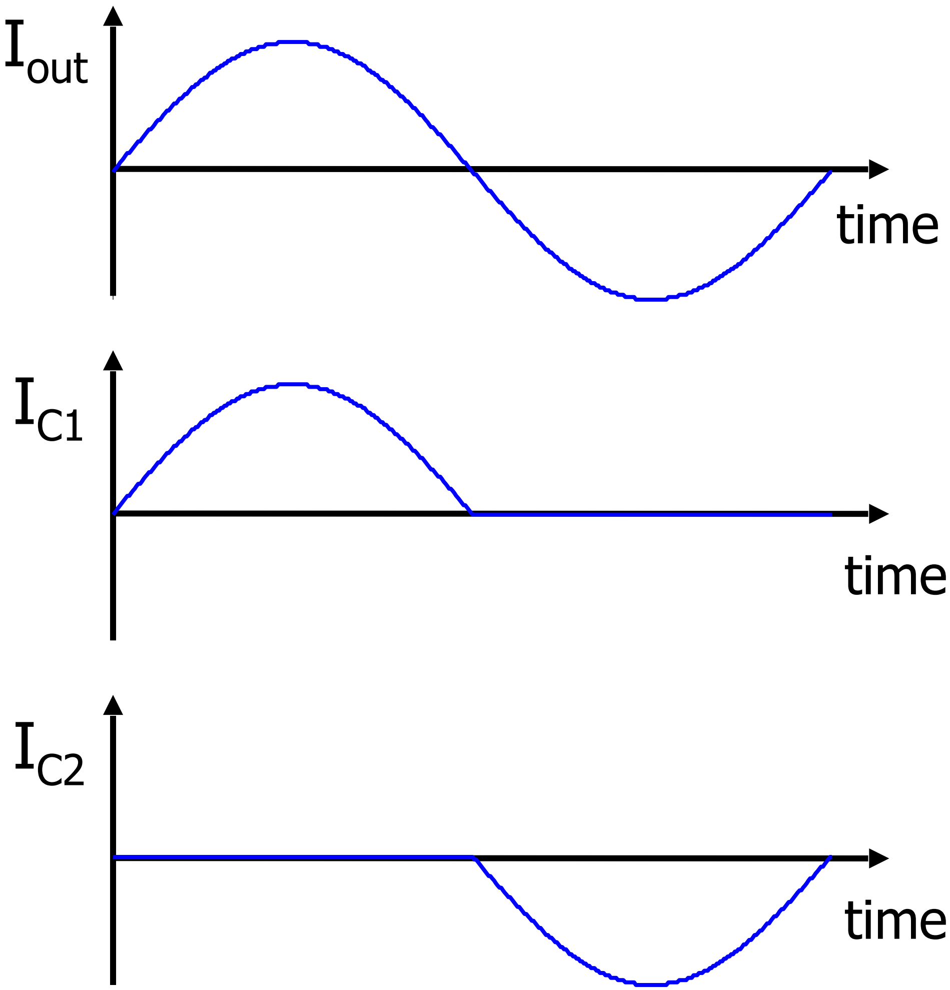


(a) During a positive half-cycle (b) During a negative half-cycle

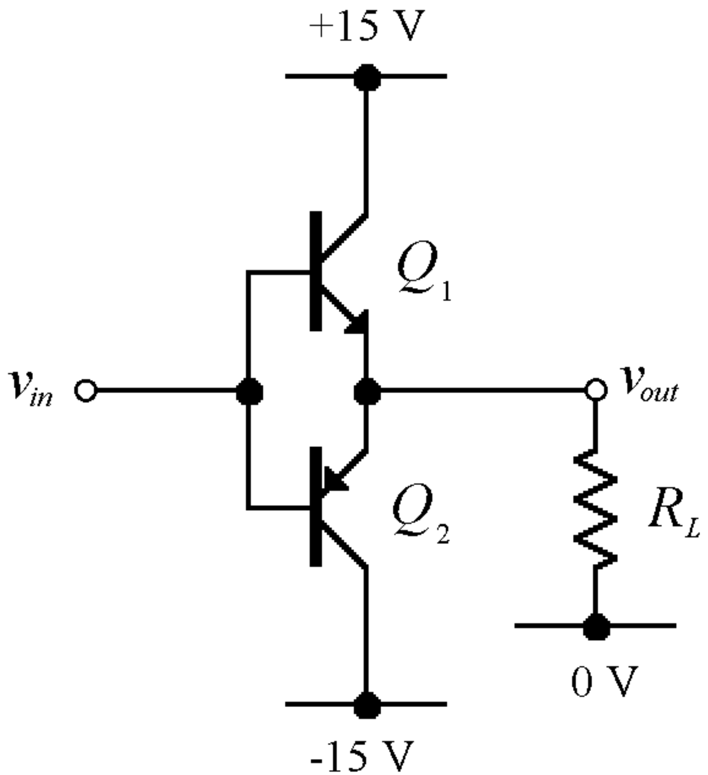
- Q_1 and Q_2 form two unbiased emitter followers
  - Q_1 only conducts when the input is positive
  - Q_2 only conducts when the input is negative
- Conduction angle per each BJT is, therefore, 180° (Class B amplifier)
- When the input is zero, neither conducts, i.e. the quiescent power dissipation is zero!

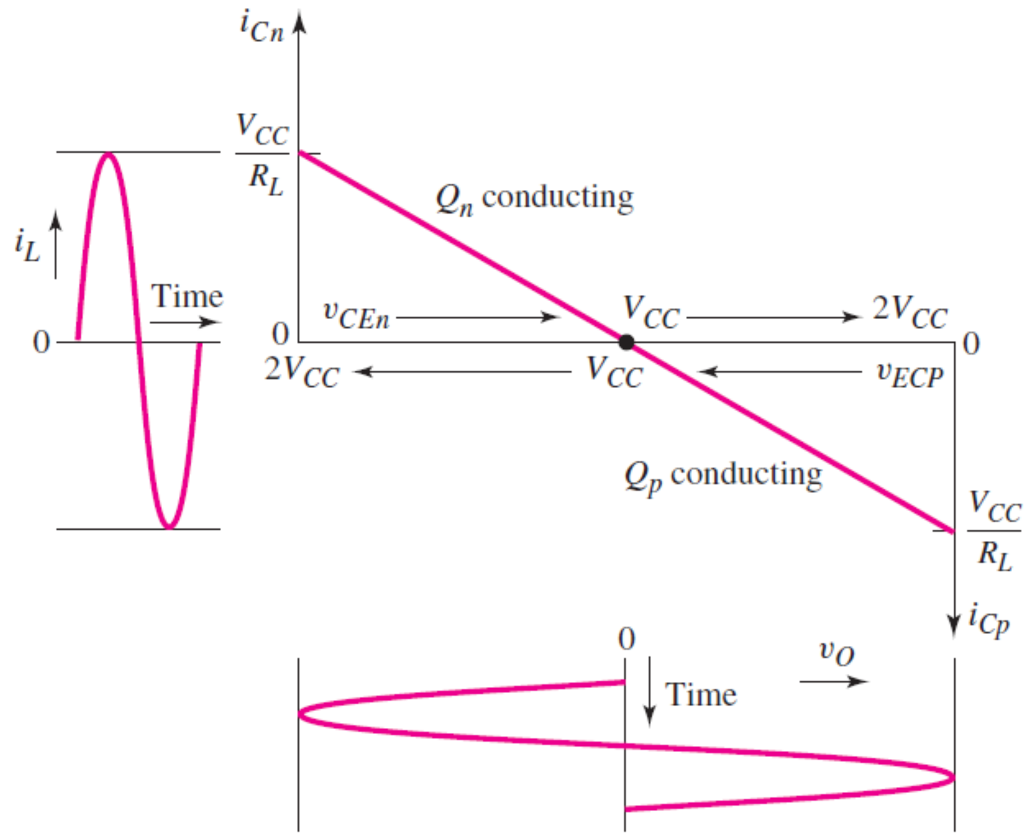
Class B Current Waveforms



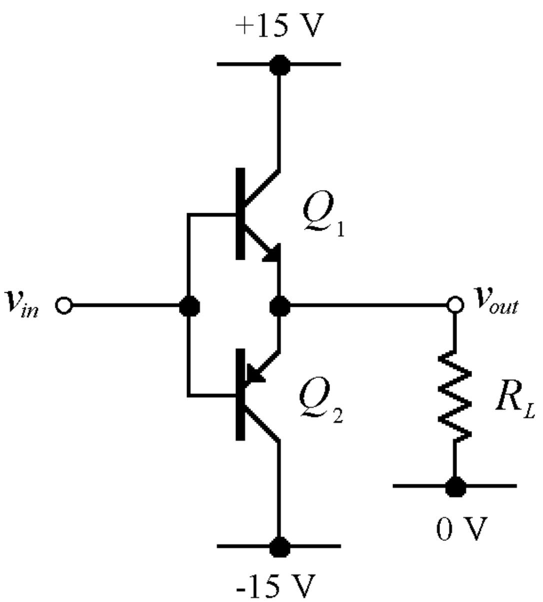


Load line of a push-pull amplifier





Efficiency of a push-pull amplifier



$$\eta = \frac{\text{signal load power}(\bar{P}_L)}{\text{supply power}(\bar{P}_S)}$$

$$v_O = V_p \sin \omega t \qquad i_o = \frac{v_o}{R_L} = \frac{V_p sin\omega t}{R_L}$$

$$\bar{P}_L = V_{o,rms} I_{o,rms} = \frac{V_{o,p}}{\sqrt{2}} \frac{I_{o,p}}{\sqrt{2}} \qquad \bar{P}_L = \frac{1}{2} \cdot \frac{V_p^2}{R_L}$$

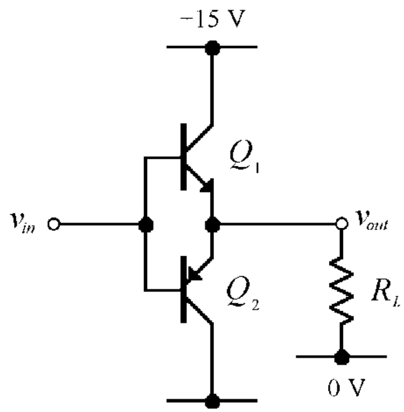
$$\bar{P}_S = \bar{P}_{S+} + \bar{P}_{S-}$$

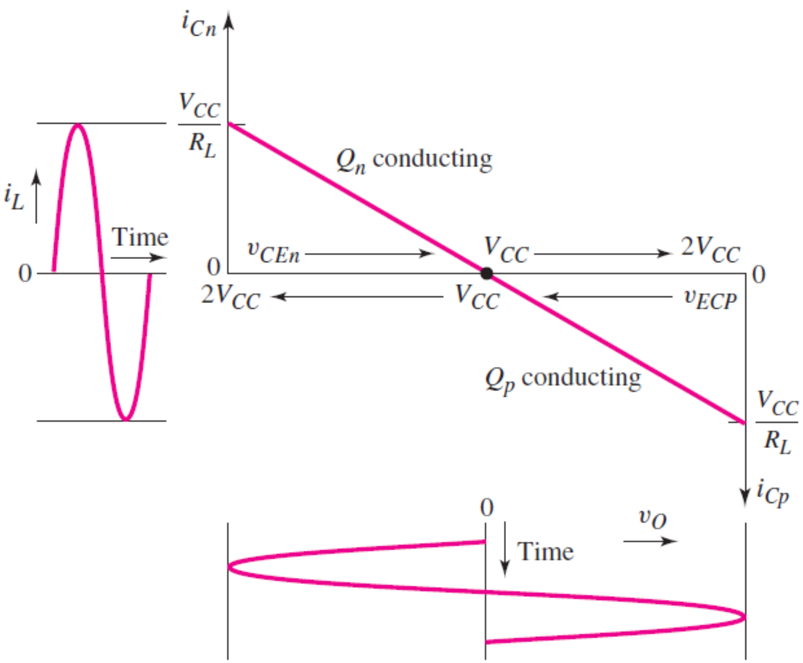
$$\bar{P}_{S+} = \frac{1}{2\pi} \int_0^{2\pi} V_{CC} I_o d\theta = \frac{1}{2\pi} \int_0^{\pi} V_{CC} \frac{V_p}{R_L} sin\theta \, d\theta$$

$$\bar{P}_{S+} = \bar{P}_{S-} = V_{CC}\left(\frac{V_p}{\pi R_L}\right) \qquad \bar{P}_S = 2V_{CC}\left(\frac{V_p}{\pi R_L}\right)$$

$$\eta = \frac{\frac{1}{2} \cdot \frac{V_p^2}{R_L}}{2V_{CC}\left(\frac{V_p}{\pi R_L}\right)} = \frac{\pi}{4} \cdot \frac{V_p}{V_{CC}}$$

Efficiency of a push-pull amplifier





$$\eta = \frac{\text{signal load power}(\bar{P}_L)}{\text{supply power}(\bar{P}_S)}$$

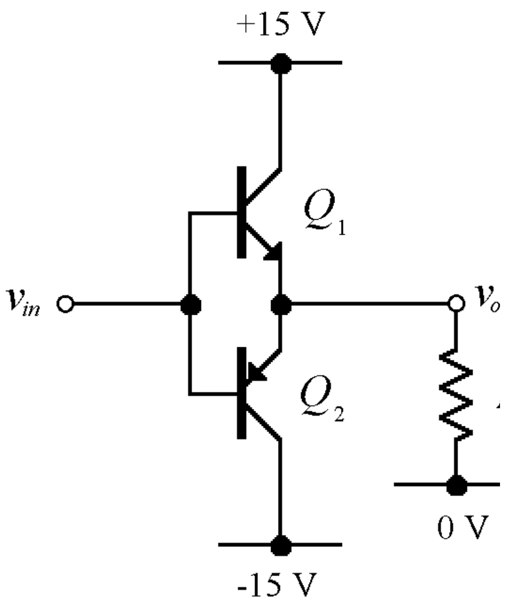
$$\eta = \frac{\frac{1}{2} \cdot \frac{V_p^2}{R_L}}{2V_{CC}\left(\frac{V_p}{\pi R_L}\right)} = \frac{\pi}{4} \cdot \frac{V_p}{V_{CC}}$$

The max possible $V_p = V_{CC}$, hence

$$\eta(\max) = \frac{\pi}{4} \Rightarrow 78.5\%$$

$$\bar{P}_L(\max) = \frac{1}{2} \cdot \frac{V_{CC}^2}{R_L}$$

Dissipated power in a push-pull amplifier



$$v_O = V_p \sin \omega t$$

where the maximum possible value of V_p is V_{CC}.

The instantaneous power dissipation in Q_n is

$$p_{Qn} = v_{CEn} i_{Cn}$$

and the collector current is

$$i_{Cn} = \frac{V_p}{R_L} \sin \omega t$$

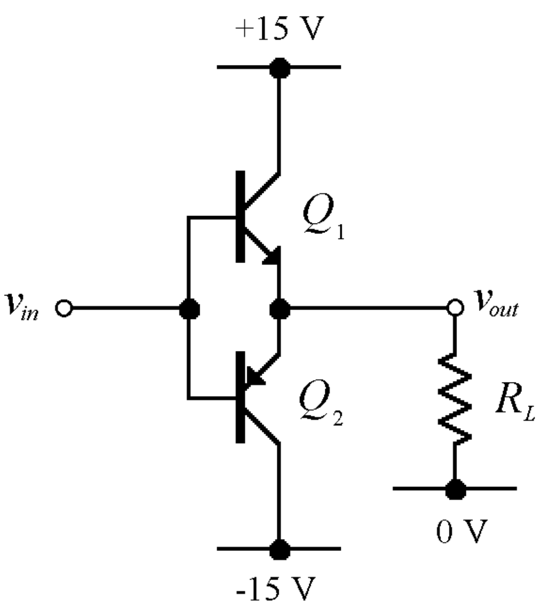
for $0 \leq \omega t \leq \pi$, and

$$i_{Cn} = 0$$

for $\pi \leq \omega t \leq 2\pi$, where V_p is the peak output voltage.

$$v_{CEn} = V_{CC} - V_p \sin \omega t$$

Dissipated power in a push-pull amplifier



Therefore, the total instantaneous power dissipation in Q_n is

$$p_{Qn} = (V_{CC} - V_p \sin \omega t)\left(\frac{V_p}{R_L} \sin \omega t\right)$$

for $0 \le \omega t \le \pi$, and

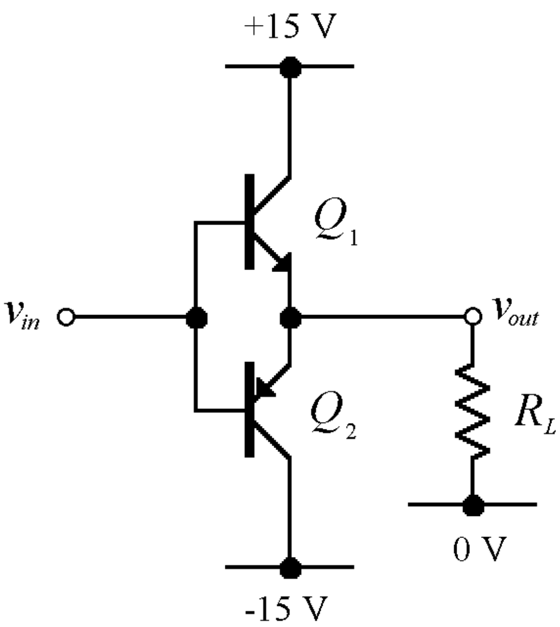
$$p_{Qn} = 0$$

for $\pi \le \omega t \le 2\pi$. The average power dissipation is therefore

$$\bar{P}_{Qn} = \frac{V_{CC} V_p}{\pi R_L} - \frac{V_p^2}{4 R_L}$$

The average power dissipation in transistor Q_p is exactly the same as that for Q_n, because of symmetry.

Efficiency of a push-pull amplifier



$$\bar{P}_{Qn} = \frac{V_{CC}V_p}{\pi R_L} - \frac{V_p^2}{4R_L}$$

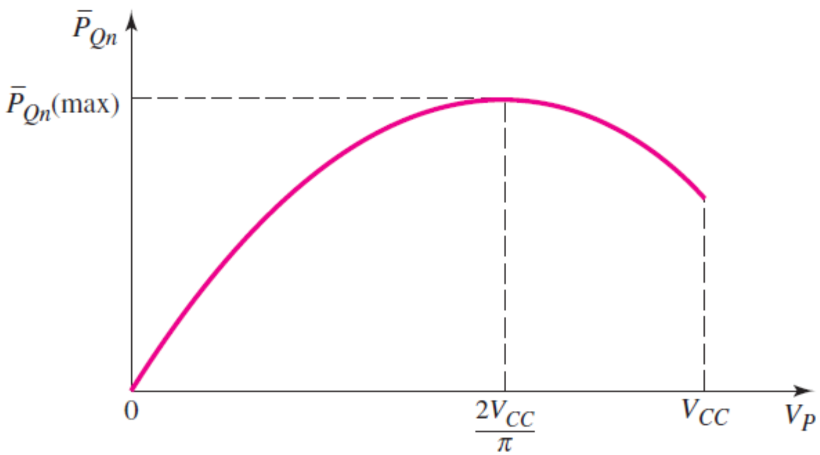


Figure 8.23 Average power dissipation in each transistor versus peak output voltage for class-B output stage

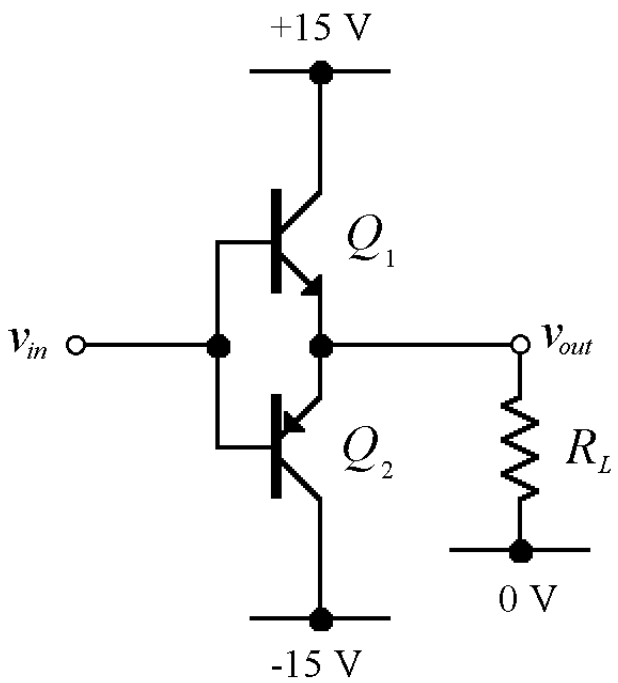
Deriving the expression obtained for P_{Qn}, and setting the derivative to zero one obtains

$$\bar{P}_{Qn}(\max) = \frac{V_{CC}^2}{\pi^2 R_L} \qquad V_p\big|_{\bar{P}_{Qn}(\max)} = \frac{2V_{CC}}{\pi}$$

Class B amplifier: pros

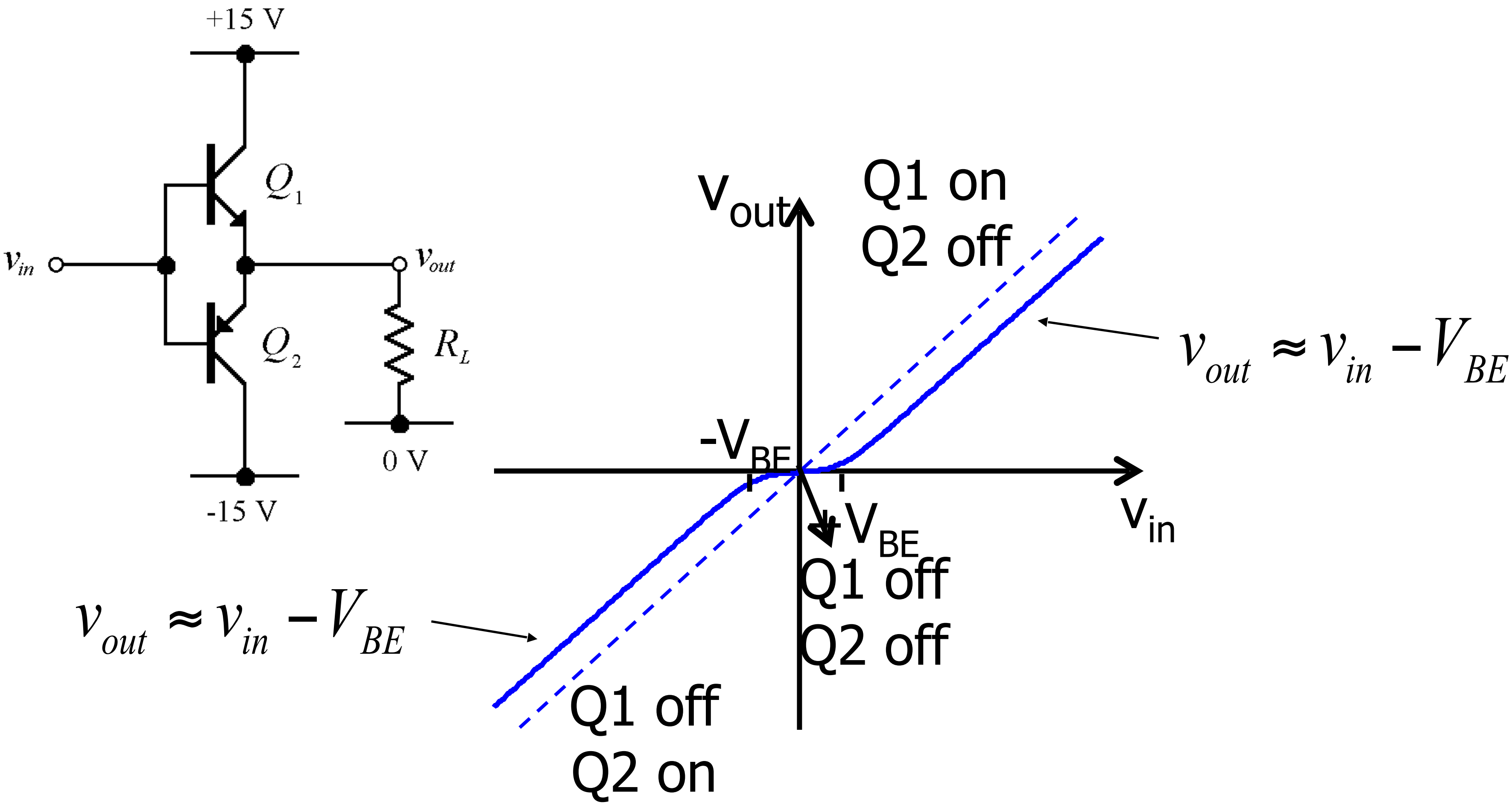
- Peak efficiency of the class B output stage is 78.5 %, much higher than class A.
- Unlike class A, power dissipation varies with output amplitude.
- Remember, there are two output devices so the power dissipation is shared between them. This eases the constraint on the power rating of the individual devices.

Cross-Over Distortion

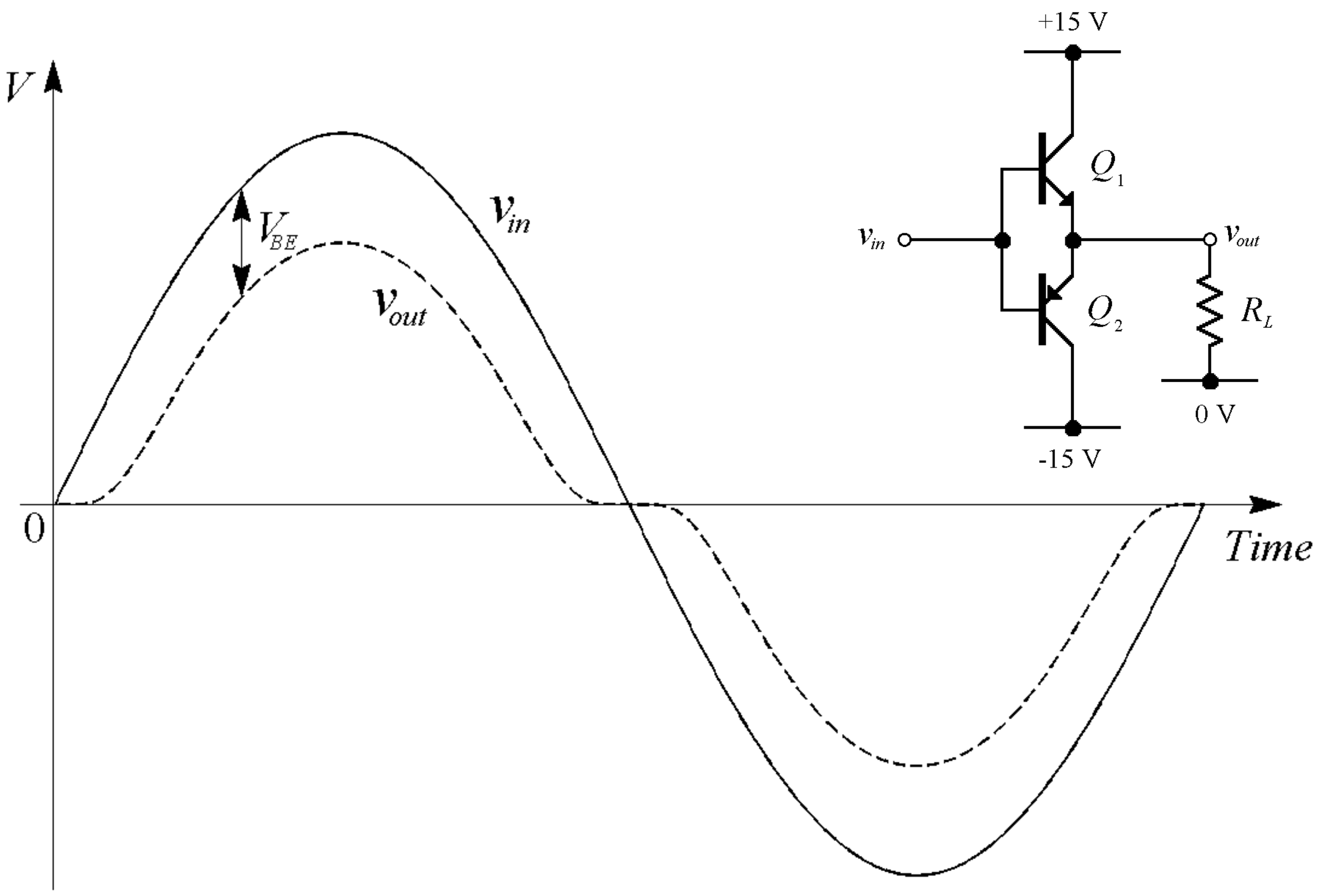


- A small base-emitter voltage is needed to turn on a transistor
- Q_1 actually only conducts when $v_{in} > 0.7$ V
- Q_2 actually only conducts when $v_{in} < -0.7$ V
- When $0.7 > v_{in} > -0.7$, Q1 and Q2 are both in cut-off and the output voltage is zero.

Actual Voltage-transfer characteristic



Effect of Cross-Over Distortion

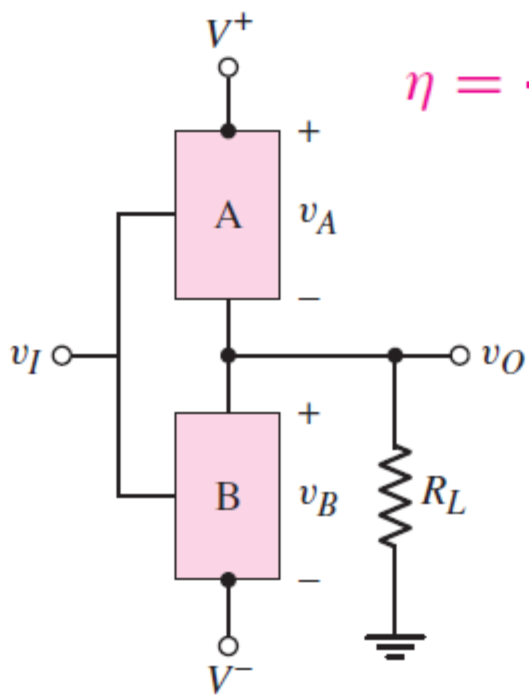


Class B amplifier: cons

- A class B output stage can be far more efficient than a class A stage (78.5 % maximum efficiency compared with 25 %).
- It also requires twice as many output transistors…
- …and it isn't very linear; cross-over distortion can be significant.

Lecture 24-In class-problem 1

For the idealized class-B output stage in Figure 8.18 in the text, show that the maximum theoretical conversion efficiency for a symmetrical square-wave input signal is 100 percent.



$$\eta = \frac{\text{signal load power}(\bar{P}_L)}{\text{supply power}(\bar{P}_S)}$$

In class-problem 1, solution

$$\overline{P_L} = \frac{V_P^2}{R_L} = \frac{\left(V^+\right)^2}{R_L}$$

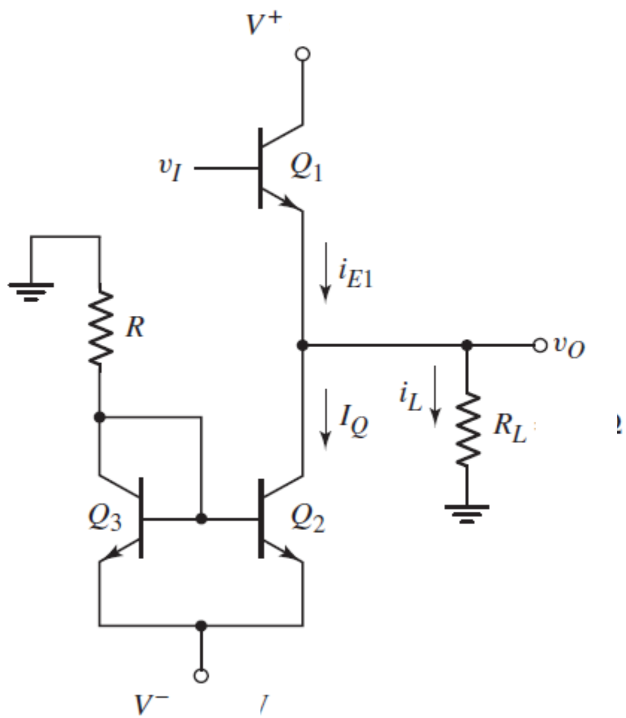
$$\overline{P_S} = \frac{1}{2}\cdot\frac{\left(V^+\right)^2}{R_L} + \frac{1}{2}\cdot\frac{\left(V^-\right)^2}{R_L},\quad V^- = -V^+$$

$$\text{So } \overline{P_S} = \frac{\left(V^+\right)^2}{R_L}$$

$$\eta = \frac{\overline{P_L}}{\overline{P_S}} \Rightarrow \underline{\eta = 100\%}$$

Take-home problem 1

Figure P8.16. Assume circuit parameters of $V^+ = 12$ V, $V^- = -12$ V, and $R_L = 20\,\Omega$. The transistor parameters are $\beta = 40$ and $V_{BE}(\text{on}) = 0.7$ V. The minimum current in Q_1 is to be $i_{E1} = 50$ mA and the minimum collector-emitter voltage is to be $v_{CE}(\text{min}) = 0.7$ V. (a) Determine the value of R that will produce the maximum possible output voltage swing. What is the value of I_Q? What are the maximum and minimum values of i_{E1}? (b) Using the results of part (a), calculate the conversion efficiency.



Take-home problem 1, solution

8.18

(a) For $\upsilon_O = -12 + 0.7 = -11.7\text{ V}, \quad I_Q = \dfrac{11.3}{0.02} + 50 = 615\text{ mA}$

$$I_{REF} = \left(1 + \frac{2}{\beta}\right) \cdot I_Q = \left(1 + \frac{2}{40}\right)(615) = 645.75\text{ mA}$$

$$R = \frac{0 - 0.7 - (-12)}{0.6475} \Rightarrow R = 17.5\,\Omega$$

For $\upsilon_O = 12 - 0.7 = +11.3\text{ V}, \quad i_L = \dfrac{11.3}{0.02} = 565\text{ mA}$

$$i_{E1}(\max) = I_Q + i_L = 615 + 565 \Rightarrow i_{E1}(\max) = 1.18\text{ A}$$

(b) $\overline{P}_L = \dfrac{1}{2} \cdot \dfrac{V_O^2}{R_L} = \dfrac{1}{2} \cdot \dfrac{(11.3)^2}{20} = 3.19\text{ W}$

$$P_S = I_Q(24) = (0.615)(24) = 14.76\text{ W}$$

Define $\eta = \dfrac{\overline{P}_L}{P_S} = \dfrac{3.19}{14.76} \times 100\% = 21.6\%$